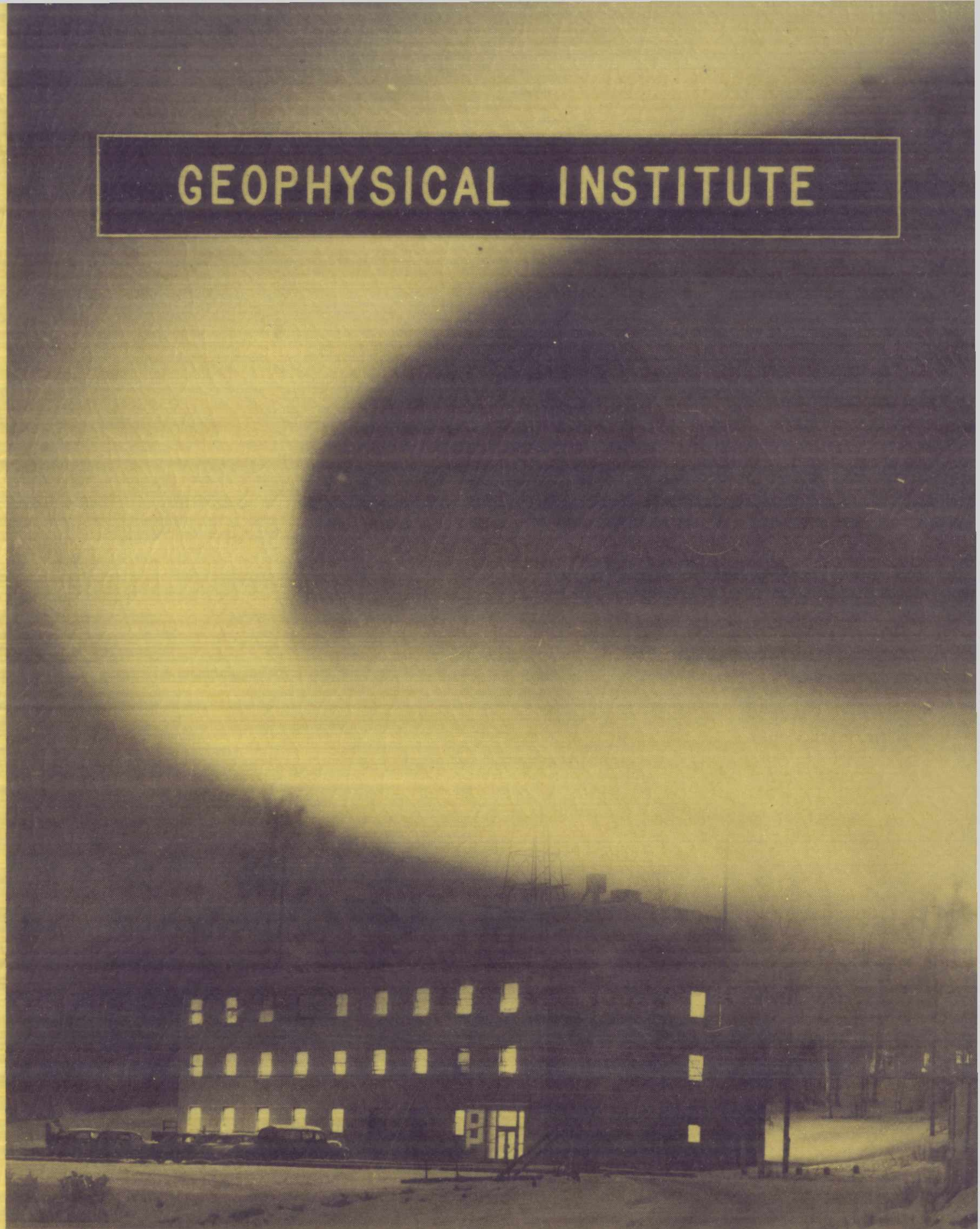

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LOW ENERGY COSMIC RAY EVENTS ASSOCIATED WITH SOLAR FLARES

by

George C. Reid and Harold Leinbach

Scientific Report No. 1
NSF Grant No. Y/22.6/327

Principal Investigator: C. T. Elvey, Director

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George C. Reid and Harold Leinbach

Geophysical Institute
University of Alaska
College, Alaska

As part of the IGY program of ionospheric investigation, the measurement of radio-wave absorption has been carried out at several high-latitude stations using the riometer (Little and Leinbach, 1959), an instrument which continuously monitors cosmic noise at a pre-selected frequency. The most important result of this program to date has been the discovery that the emission of fast particles from the sun following a flare is a much more frequent occurrence than had hitherto been suspected. Following the great cosmic-ray-producing flare of February 23, 1956, very strong radio-wave absorption occurred in high latitudes for a period of about three days, and was noted by Little and Leinbach (1958) and discussed in some detail by Bailey (1957), who observed the absorption on VHF ionospheric forward scatter links in the arctic. Reid and Collins (1959) later gave details of two more of these events, in July and October 1957, and in a discussion of the various classes of abnormal absorption events found in high latitudes (polar blackouts) proposed the name 'Type III absorption' for these events. They suggested that most of the features of Type III events could be explained by assuming that the upper atmosphere was ionized by fast protons emitted from the sun following a major flare; this suggestion has also been made independently by Bailey (1959) and Hultqvist (in press (a)).

The riometer can be shown to be an extremely efficient detector of vertically incident protons in the energy range from 5 to 50 MeV; rough calculations show that a flux of about 10 protons per cm^2 per second could readily be detected if the energy is about 10 MeV. It can be shown that for a given amount of ionization, the radio wave absorption is a maximum if the local ionospheric collisional frequency is equal to the angular frequency of the radio waves. For the riometer, operating at a frequency of 27.6 Mc/s, this occurs at a height of about 50 km; the ionization produced by protons whose penetration depth is either more or less than this value will cause less absorption than that due to protons reaching exactly this level.

Confirmation of the proton theory came from balloon observations of cosmic rays over Fort Churchill by Anderson (1958) during a Type III event on August 22, 1958. These observations definitely showed the presence of a flux of protons at balloon heights whose energies were not high enough to allow penetration to ground level. Many such balloon flights have been made during subsequent events at both high and middle latitudes, notably by the University of Minnesota and State University of Iowa groups, and reference is made to these in Table I. In the period from May 1957 through July 1959, a total of 24 Type III events have been observed using the riometer technique; this figure may be contrasted with the five occasions in the history of cosmic ray recording on which increases of intensity associated with solar flares have been recorded at ground level. The relevant details of these Type III events have been compiled in Table I. The normal sequence of events is as follows:

(1) A major solar flare occurs, usually accompanied by a short-wave fadeout over the sunlit hemisphere of the earth; these fadeouts are caused by electromagnetic radiation from the flare, and are recorded by the riometer if it happens to be on the sunlit hemisphere. They are referred to in the table as SCNA's (sudden cosmic noise absorption).

(2) The flare is almost without exception followed by a strong low-frequency solar noise storm, often lasting for several hours; this is also

recorded by the riometer when the sun is above the horizon. The column in the table headed 'Solar activity at 27.6 Mc/s' refers solely to riometer observations made in Alaska, and the absence of data for some events does not mean that a noise storm did not occur.

(3) Within a few hours after the flare, the Type III absorption sets in over the entire polar cap, the actual onset often being obscured by the solar noise storm; the absorption reaches a maximum within a few hours, then decays slowly during the following few days.

(4) After a day or two a sudden commencement magnetic storm almost invariably occurs, often accompanied by intense auroral activity.

The starting times listed in Table I should be taken as upper limits, since it is quite possible that more sensitive equipment would have shown weak absorption occurring before these times. Similarly, the durations should be taken as merely lower limits, since the decay of the absorption is quasi-exponential, and a precise duration is undefinable.

The flare data have been taken from the CRPL tabulations of Solar-Geophysical Data issued monthly by the National Bureau of Standards. Two important points can be noted from this collection of material;

(1) Of the 24 events listed, the identification of the corresponding flare is considered to be certain in 13 cases, and highly probable in a further 5 cases. Examination of the heliographic positions of these 18 flares shows that 12 occurred to the west of the solar central meridian and 6 to the east. Assuming the entire solar flare population during the period to be symmetrically distributed about the central meridian, the probability of this asymmetric distribution of cosmic-ray flares occurring by chance is only 7%. Thus, although the statistics are not as yet really adequate, there is a clear indication

that solar cosmic-rays originating on the western half of the visible disc can reach the earth more readily than those from the eastern half.

This can be taken as favoring the hypothesis of the outward extension of a solar magnetic field by low-velocity charged particles traveling radially outward from the sun, as has been suggested by Parker (1958a). The rotation of the sun will produce a curvature of the particle streams (Chapman, 1929) and consequently of the lines of force, which will be convex towards the west. The fast low density protons suddenly ejected into this field will tend to travel along the lines of force, so that protons originating to the west of the solar central meridian can reach the earth more easily than those from the east. With the limited amount of data now available, it is impossible to do more than present this as a tentative suggestion.

(2) The duration and intensity of these events at College are less than at the more northerly stations, and examination of the recordings from Farewell, to the south of College, shows that Type III events, with a few exceptions, were either very weak or absent. Since the difference in geomagnetic latitude between College and Farewell is only $3^{\circ}.3$, this suggests that College is normally close to the southerly border of the region affected by protons penetrating only to the lower ionosphere, and that this border is very sharply defined. Those few cases in which strong Type III absorption has been observed as far as 7° south (geomagnetically) of College occurred only after the onset of unusually strong magnetic storms of the sudden commencement type. This behavior seems to indicate that on these occasions the geomagnetic field became sufficiently perturbed to allow the lower energy protons to reach latitudes normally forbidden by a cut-off mechanism of the Störmer type (Freier and others, 1959).

However, there is a striking similarity in the form of the records from Barrow and Thule, which are separated in geomagnetic latitude by about 19°. This agrees with the observations of Bailey (1959) on the February 23, 1956 event, and can be explained by a sharp flattening in the particle energy spectrum below the energy corresponding to the Störmer cut-off at 70° geomagnetic latitude. Another possible explanation, however, may lie in the confinement of the geomagnetic field within a finite region due to the impact of the streams of low energy particles responsible for setting up the interplanetary magnetic field. Geomagnetic field lines from the polar regions, which would normally cross the equatorial plane in regions of low magnetic field intensity, would become very greatly disturbed under these conditions, and may link up with the solar stream field lines to preserve continuity of the field, thus providing a natural path for the fast protons. Since these geomagnetic field lines are the ones which intersect the earth to the north of the auroral zone (Chapman and Ferraro, 1931, 1932; Parker 1958b), we might expect to see effects approximating those predicted by the Störmer theory of charged particles in a dipole field only to the south of the auroral zone. To the north we would expect to see more intense effects which would also be much more uniform, since the energy selection provided by the Störmer cut-off would no longer apply.

This suggestion is rather difficult to justify completely, but it does have the considerable merit of placing the low-latitude limit of the uniform polar cap absorption at the position of the auroral zone. Any theory which explains the uniformity by a flattening in the that solar cosmic-rays originating on the western half of the visible disc can reach the earth more readily than those from the eastern half.

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proton energy spectrum below a certain energy must also explain the remarkable coincidence that this energy nearly always corresponds to a Störmer cut-off at just the latitude of the auroral zone. Since the energy spectrum of the protons emitted from the sun can in no way be influenced by the geomagnetic field, such an explanation would be extremely difficult.

The work described here has been supported by the National Science Foundation as part of the International Geophysical Year program under IGY Grants 6.20, 1.43 and Y.22.6. The initiation of the U.S. IGY riometer program is due to Dr. C. G. Little, and the successful operation of the program would not have been possible without the constant support of the many field station operators.

TABLE I: Type III Polar Cap Absorption Events:

Date	Starts (UT)	Duration (greater than: hours)	Max. absorption at 27.6 mcs. (db.)	Solar activity at 27.6 mcs.
1957				
May 19	0200	10 (B)	1	N.S.[4] 0020-0045
		6 (C)	1	
Jun 22	by 1000	x	x	-
Jul 3	by 1100	46 (C)	6	-
Jul 24	2015	11 (C)	2	N.S. 1815-1935
Aug 29	1300	77 (C)	9	-
Sep 2	by 2100	32 (C)	9	N.S. 1440-2230
Sep 12	by 1200	18 ($80^oN,S$)[b]	-	
			0.5 (C)	
Sep 21	by 1930	31 (C)	5	
Sep 26	by 2315	29 (C)	2	N.S. 1930-2315
Oct 21	by 0700	13 (C)	5	
1958				
Feb 10	by 0700	30 ($80^oN,S$)[b]	-	
		-	>12 (C)	
Mar 25	by 2230	96 (FY)	12 (C)	
Apr 10	1130	30 (C)	3 (C)	
		40 (FY)	4.5 (FY)	
Jul 7	0130 (T)	78 (C)	>15	SCNA[5] 0030
		120 (B)	>15	N.S. 0040-0210
		x (T)	>15	
Jul 29	0405 (T)	4 (C)	0.7	SCNA 0303
		30 (B)	1	N.S. 0335-0450
		22 (T)	1.5	
Aug 16	0600 (T)	x (C)	x	SCNA 0435
		60 (B)	13	N.S. 0440-0515
		56 (T)	>15	

: May 1957 - July 1959.

Probable flare				References[3]	
Time (UT)	Imp.	Heliogr. position	Plage region	Radio data	Balloon or satellite data
0800	3+	N13 W40	4039	a	
1816	3	S24 W22	4070		
1031	3	S24 E22	4125		
1313	3	S25 W36	4125		
0709[1]	2	N12 W15	4134	b	
1332	3	N13 W08	4152		
1907	3	N26 E15	4159		
1637 (20th)	3+	S25 W45	4189	a	
2108 (9th)	2+	S13 W14	4400	b	
0950 (23rd)	3+	S15 E80	4476	c	c
1010	1+	N18 W78	4485		
0039	3+	N24 W02	4634	d,e,f,g	h
0303	3	S14 W43	4659	i	
0432	3+	S14 W53	4686	d,e,f	j

TABLE I - Continued

Date	Starts (UT)	Duration (greater than: hours)	Max. absorption at 27.6 mcs. (db.)	Solar activity at 27.6 mcs.	Probable flare: Time (UT)	Probable flare: Imp.	Probable flare: Heliogr. position	Probable flare: Plage region	References[3]: Radio data	References[3]: Balloon cr satellite data
Aug 21	1500(B)	x (C)	3							
		19 (B)	3							
		x (T)	x							
Aug 22 by	1700[2]	80 (C)*	>10	N.S. 1500-2100	1417	3	N21 W08	4708	e,k	j,k,l
		80 (B)*	> 9							
		80 (T)*	9							
Aug 26	0100(T)	57 (C)	>10	N.S. 0020-0145	0005	3	N20 W54	4708	d,e,f	j
		89 (B)	12							
		71 (T)	>13							
Sep 22	1430(B)	x (C)	4		0741[1]	2+	S17 W42	4765		
		68 (B)	4		1014	2	N18 W65	4756		
		82 (T)	4							
1959										
May 11	0130	92 (C)	>15	SCNA 2100(10th)	2055	3+	N23 E47	5148	m	m
		200 (B)	>15	N.S. 2118-2315 (10th)	(10th)					
		190 (T)	>15							
				SCNA 2010 (11th)	2006	2+	N08 E39	5148		
				N.S. 2020-2135 (11th)	(11th)					
Jul 10[6]	0700(T)	90 (C)*	>15	N.S. 2046-0400	1937(9th)	2+	N19 E67			
				SCNA 0215	0210 (10th)	3+	N22 E70			
Jul 14[6] by	0700	51 (C)	>15	SCNA 0332	0342	3+	N16 E07			
				N.S. 0340-0700						
Jul 16[6] by	2250	34 (C)	>15	SCNA 2119	2115	3+	N08 W26			
				N.S. 2125-0015						

* Event still in progress at start of subsequent event.
1. Flare identification dubious
2. Anderson (1958) reports detection of protons at balloon heights as early as 1525 U.T.
3. See lettered footnotes
4. N.S. - Solar noise storm
5. SCNA - Sudden cosmic noise absorption
6. Brown (1959) has reported detection of particles at balloon heights over College during these events. Winckler (1959) has reported similar observations over Minneapolis and Churchill.

(C)-College, Alaska
(B)-Barrow, Alaska
(T)-Thule, Greenland
(FY)-Fort Yukon, Alaska

a: Reid and Collins, 1959
b: Hakura and others, 1958
c: Freier and others, 1959
d: Hultqvist, in press (b)
e: Hultqvist and Ortner, 1959
f: Hultqvist and others, 1959
g: Harang and Troim, 1959
h: Brown, 1959
i: Leinbach and Reid, 1959
j: Rothwell & McIlwain, 1959
k: Anderson & others, 1959
l: Anderson, 1958
m: Ney and others, in press

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